

THE MAGNETIC PROPERTIES OF  
BINARY THALLIUM ALLOYS BEFORE  
AND AFTER HEAT TREATMENT IN  
A VACUUM

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field.

(2) Diamagnetic - Those which come to rest with their axes at right angles to the direction of the lines of force in field.

Later, this division was modified according to the manner in which the substances affect the lines of force of the magnetic field.

1. (a) INTRODUCTION

The science of Magnetism has developed from the observation, many centuries ago, that loadstone attracted iron, and until 1778 when Brugmans<sup>1</sup> noticed that Bismuth was repelled by a magnet, the metals of the Iron group were considered to be the only ones possessing magnetic properties. Becquerel<sup>2</sup>, in 1827, observed a similar action with Antimony, and in 1845, Faraday<sup>3</sup> showed that a sufficiently strong magnetic field has an action on practically every substance.

He divided substances into two classes, according to the position they took up when suspended in a magnetic field.

(1) Paramagnetic - Those which tend to come to rest with their axes parallel to the field.

(2) Diamagnetic - Those which come to rest with their axes at right angles to the direction of the lines of force in field.

Later, this division was modified according to the manner in which the substances affect the lines of force of the magnetic field.

The fundamental characteristics of dia and paramagnetha were later established by R. Curie.

1. (a) Lines of force concentrated to a large extent -  
ferromagnetic.
- (b) Lines of force concentrated to a very small extent -  
paramagnetic.
2. Lines of force slightly dispersed - diamagnetic.

Members of class 1. are Fe, Co, Ni, and certain of their alloys and compounds. All other substances belong to either class 2. or class 3.

When a body is placed in a magnetic field it either concentrates or disperses the lines of magnetic force. The Intensity of Magnetisation is proportional to the strength of the field.

$$I = KH$$

where

I is the Intensity of magnetisation per cc.

H is the field strength or force per unit pole.

K is the magnetic susceptibility or coefficient of magnetisation.

Wiedemann.  $\therefore K = \frac{I}{H}$  of Iron, Cobalt and Manganese

i.e. the ratio of the magnetic moment per cc. at any point within the body to the field H (provided that the body is of such dimensions that the intensity may be regarded as uniform.

The fundamental characteristics of dia and paramagnetism were later established by P. Curie.<sup>4</sup>

By plotting atomic weights as abscissae and atomic volumes as ordinates, a curve with well defined maxima and minima is obtained, and Stefan Meyer showed that paramagnetic substances fall on the descending and diamagnetic on the ascending branches of the curve.

Becquerel,<sup>5</sup> Tyndall, Reich<sup>6</sup> and others showed that  $K$  is independent of the field  $H$ . This was supported later by Wiedemann,<sup>7</sup> Ettinghausen,<sup>8</sup> Curie,<sup>9</sup> Stefan Meyer<sup>10</sup> and others, but it is not true of the ferromagnetic metals.

Other investigations found a relation between  $K$  and  $H$  in some cases. Honda,<sup>11</sup> for example, did so in his study of forty-three of the elements. This, however, was shown to be due to traces of iron in the specimens, and for iron-free specimens  $K$  was proved independent of  $H$ .

The relation between magnetic susceptibility and temperature was studied by Faraday,<sup>12</sup> Plücker<sup>13</sup> and others who showed that as the temperature increases both paramagnetism and diamagnetism decrease.

Wiedemann,<sup>14</sup> in the case of Iron, Cobalt and Manganese found that  $K$  varies inversely as the absolute temperature.

In 1895 Curie<sup>15</sup> established the law now known by his name, which stated that with the exception of Antimony and Bismuth,  $K$  is independent of temperature for diamagnetic bodies, while for paramagnetic bodies,  $K$  varies inversely as the absolute temperature. He also showed that at

high temperatures ferromagnetic substances tend to pass into paramagnetic substances. The temperature at which this transition takes place is known as the Curie point.

In 1905 Langevin<sup>16</sup> obtained an expression for the variation of paramagnetic susceptibilities with temperature which, for small fields, reduced to Curie's law.

Urbain<sup>17</sup> examined a large number of binary mixtures and found that the value of the susceptibility depends directly on the amount of each constituent present, i.e. the property is strictly additive.

Stefan Meyer<sup>18</sup> gave the following rules as the result of his investigations:

- (1) Two diamagnetic elements always produce a diamagnetic binary compound.
- (2) Two paramagnetic elements usually produce a paramagnetic compound.

Until nearly a century ago magnetism and electricity were considered to be entirely independent phenomena, but in 1819 they were linked by the discovery of Øersted that a compass needle was deflected when placed parallel to a wire carrying an electric current.

The work of Arago, Biot and Ampère showed that there was a mutual magnetic action between currents and magnets and currents and currents.

Since the establishment by Faraday of the laws of Electro Magnetic Induction we conclude that an electric

current is surrounded by lines of magnetic force, and that every closed electric circuit is equivalent to a magnet of definite moment.

The modern theory that the atom consists of a heavy nucleus surrounded by electric charges moving rapidly in closed orbits makes clear the origin of the magnetic properties of matter.

The foundation of the modern electronic theory of magnetism was laid in 1905 by Langevin,<sup>19</sup> who regarded the effects as due to rotating electrons. Every electronic orbit must have a magnetic moment, but by a suitable arrangement these may neutralise one another, thus giving a diamagnetic effect and a resulting moment of zero. It has been shown that the establishment of an external field will so modify the orbits that a diamagnetic effect is produced. This is common to all matter, whether diamagnetic or not, but if the orbital moments do not neutralise one another the atom is paramagnetic and the paramagnetism will completely mask the diamagnetism.

Paramagnetism is found only amongst those elements which contain incomplete electronic groups; those with closed configurations, i.e. with completed electronic orbits, balance magnetically and are diamagnetic.

A knowledge of the magnetic properties of elements, compounds, and mixtures has, in many cases, led to interesting results regarding the structure of the atom



and molecule.

The investigation of the magnetic susceptibility of alloys was stimulated by the discovery in 1903 of the Heusler<sup>20</sup> alloys. Manganese alloys containing no ferromagnetic metals were found to be strongly magnetic. The addition of Aluminium, Tin, Arsenic, Antimony and Bismuth to Manganese - Copper alloy containing 30% Manganese produced a great increase in magnetic properties.

Sir Robert Hadfield's<sup>21</sup> work in 1917 on certain Manganese Steels showed that the addition of Carbon, Tungsten, Manganese, Silicon, Chromium, Copper and Nickel to certain Steels altered the magnetic properties considerably.

In 1927 Spencer and John<sup>22</sup> investigated several binary alloys, the majority of which showed well defined compounds. Measurement of Lead-Gold alloys showed the existence of  $Pb_3Au_2$  and this result was confirmed by Von Maly<sup>23</sup> from a study of specific volume curves. In the case of the system Aluminium - Tin, two paramagnetic metals give rise to diamagnetic alloys, as shown by the curve.

A repetition of this work by Y. Shimizu<sup>24</sup> in 1932 failed to confirm these results. After preparing and measuring the alloys in air, Shimizu annealed them in vacuo for three hours and remeasured them. He found that his original curve was considerably modified.

He then prepared his alloys in vacuo, and this time the graph obtained was practically a straight line. He therefore suggested the irregular curves obtained by Spencer and John were due to adsorbed gases, and were not a true indication of compound formation.

The following work was an attempt to repeat the results obtained by Shimizu. For this reason a system well known to form compounds, viz, Bismuth - Thallium, was chosen, and the measurements made as described.

The system Cadmium - Thallium in which other methods had failed to indicate compound formation was also investigated.

#### PREPARATION OF THE ALLOYS

Metallic Thallium readily combines with atmospheric oxygen with the formation of Thallous Oxide, a black compound fusible at  $500^{\circ}\text{C}$ . It was therefore advisable to consider the range of temperature needed for the formation of the various alloys.

The plan of work consisted of the examination of binary alloys of Thallium with metals with which it is completely miscible in all proportions in the liquid state, and which melt below  $500^{\circ}\text{C}$ .

An examination of the freezing-point curves given

in Landolt-Börnstein's Physikatisch-Chemische Tabellen, 1923 Edition, page 527 et seq., led to the choice of the following binary systems for investigation:

- (a) Thallium - Bismuth.
- (b) Thallium - Cadmium.

#### MATERIALS

Pure Bismuth and Cadmium were supplied by Kahlbaum. The Bismuth, supplied in sticks, was sawn into pieces of suitable size with a metal saw. The Cadmium was granulated by melting and pouring into water. The Thallium, in the form of sticks, was supplied partly by Kahlbaum and partly by Harringtons. On examination it was found to be contaminated by Bismuth and by small quantities of Lead.

#### PURIFICATION OF THALLIUM

The sticks of crude Thallium were dissolved in dilute Sulphuric Acid, and the resulting solution filtered and allowed to crystallise, when needle-shaped crystals of Thallous Sulphate were obtained. These were dissolved in water slightly acidified with Sulphuric Acid, and the solution treated with Hydrogen Sulphide until no further precipitation took place. The solution was again filtered and excess Hydrogen Sulphide removed by boiling.

The cold solution was electrolysed in a glass trough between a platinum foil anode and a platinum wire cathode. To prevent the Thallium being contaminated with the Thallous Oxide deposited at the anode, this electrode was supported in a shallow glass dish.

Pure Thallium was deposited at the cathode in flat silvery plates of a leaf-like formation. It was taken up, washed, and kept under freshly boiled distilled water until required, when it was dried over Calcium Chloride in a vacuum desiccator. The electrolytically prepared Thallium gave no reaction for Lead or Bismuth. Traces of Bismuth in a compound can be detected by the use of Cinchonine, which, in the presence of Potassium Iodide gives an orange precipitate.

1 gram of Cinchonine was dissolved in 100 ccs of warm water acidified with Nitric Acid, and after cooling, 2 grams of Potassium Iodide were added. A filter paper was then spotted with this reagent, and then with a solution of the electrolytically prepared Thallium in Nitric Acid. No orange colour was observed, so the Thallium was taken as being free from Bismuth.

The metal was examined for Lead by means of Diphenyl - Thiocarbazon. A solution of this reagent in Carbon Tetrachloride gives a brick red colouration with neutral or slightly alkaline solutions containing Lead.

A Nitric Acid solution of the Thallium was neutralised with Ammonia and a few drops of the reagent were added. No red colouration was observed, so the Thallium was considered to be free from Lead.

#### BISMUTH - THALLIUM ALLOYS

Melting point range, Bismuth  $271^{\circ}\text{C}$ , Thallium  $307^{\circ}\text{C}$  with minima at  $190^{\circ}\text{C}$  and  $194^{\circ}\text{C}$ .

Nine alloys were made, i.e. 10% Tl, 90% Bi, 20% Tl, 80% Bi, and so on expressed in weight per cent, and in each case the weight of mixture taken was about 60 grams. Alloys containing between 10 and 50% Thallium were made by melting the required weights of the metals in a graphite crucible over a bunsen flame, and the molten mixture thoroughly stirred with a silica rod. The mixture was then poured into hollow carbon rods closed at one end by plaster of Paris caps. In this way cylindrical rods of about 0.68 cms diameter were obtained.

The alloys containing 60 to 90% Thallium were melted in an atmosphere of Nitrogen. (See diagram 1.).

The metals were placed in a crucible covered with a lid, through which passed two short pieces of glass tubing. Nitrogen from a cylinder was passed through the crucible. When the metals were molten the lid was removed, the mixture stirred quickly, and cast into

(100)

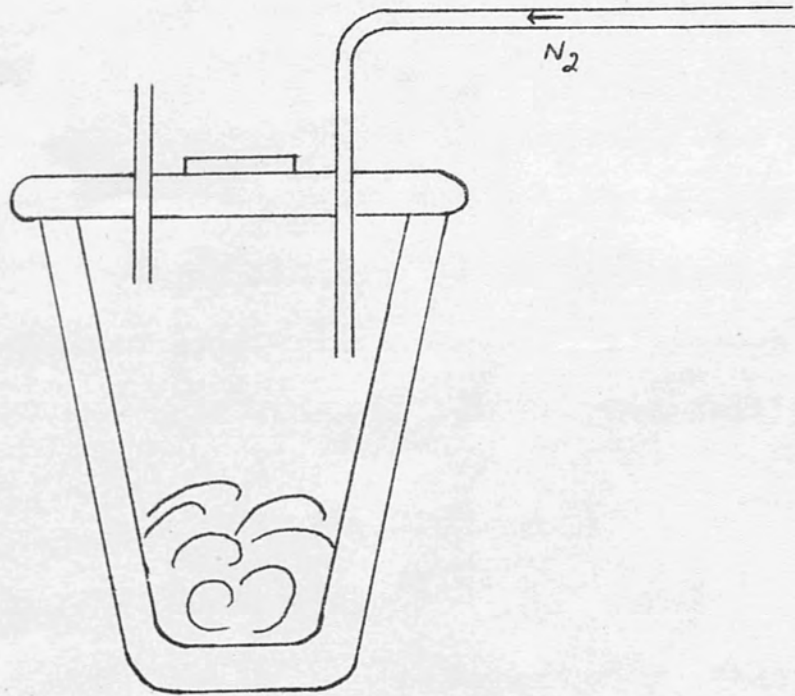


DIAGRAM I.

carbon moulds as before.

Later it was found necessary to examine alloys of composition between those already made. These were prepared similarly by adding the requisite quantities of Bismuth to existing alloys. The alloys with a low percentage of Thallium were silvery in colour and very brittle, so that great care had to be taken in chipping off the moulds. When the Thallium content was over 40%, the alloys became much tougher, and those with a higher percentage of Thallium had a dull surface due to rapid oxidation. Also, these higher percentage alloys tended to contract on cooling, and slipped easily out of the moulds.

#### CADMIUM - THALLIUM ALLOYS

Range of melting point, Cadmium  $321^{\circ}\text{C}$ , Thallium  $307^{\circ}\text{C}$ , minimum at  $208^{\circ}\text{C}$ .

The entire range of alloys was made by melting the metals in air and pouring into graphite moulds.

All the Cadmium alloys were very tough and tended to contract on cooling. Those with a high percentage of Cadmium were bright and silvery, while those with a high percentage of Thallium were very much like Lead in appearance.

In no case was any such colour observed, and as the reagent is sensitive to

### PREPARATION OF RODS OF PURE METAL

In the case of Bismuth and Cadmium the metals were melted in air and cast as above. The Thallium was melted in Nitrogen as previously described.

### PREPARATION OF PORTION OF SPECIMEN FOR MEASUREMENT

In all cases the cylinders of alloys were treated as follows:- a portion about 7.4 cms. long was cut with a metal saw from the centre of each cylinder, and small pieces from either side of this portion were analysed.

When the results of the analysis showed that the composition of the ends of the rod did not differ by more than 0.1 per cent of the mean value, the centre piece was prepared for measurement. It was rubbed with sand-paper until it fitted easily into the susceptibility tube, after which it was washed with dilute Hydrochloric Acid, distilled water, and dried. The composition of the rod was taken as the mean of that of the two ends.

Portions from either end of the rod were then tested for traces of Iron. The alloy was dissolved in dilute Nitric Acid and the solution made alkaline with Ammonia. Two drops of Thioglycollic Acid were then added, when the presence of Iron would have been indicated by the appearance of a purple red colour. In no case was any such colour observed, and as the reagent is sensitive to



a concentration of  $10^{-6}$ , it was concluded that if any iron was present, it was less than one part per million.

The cylinders of pure metal were treated in the same way. The main object of washing with dilute Hydrochloric Acid was to remove particles of Iron which had possibly been left in the cutting of the alloy. This precaution has been previously shown by Hadfield and Cheneveau to be very necessary.

#### ANALYSIS OF ALLOYS

The Thallium, in both systems, was estimated as the Chromate by the method described in Mitchell and Ward, (Modern Methods in Quantitative Chemical Analysis). In order to ascertain whether or not the solubility of Thallous Chromate appreciably affected the results, a parallel estimation as Iodide was made. As no difference was observed, the Chromate estimation was used throughout.

(a)

In the Bismuth - Thallium alloys it proved necessary to remove the Bismuth before attempting to estimate the Thallium.

This was done by dissolving the portions of alloy in dilute Nitric Acid, and neutralising with a solution of Sodium Carbonate. On boiling, the whole of the Bismuth was precipitated as a basic compound. This was filtered off and washed with boiling water until the washings gave

no precipitate on treatment with Potassium Iodide.

The volume of the filtrate was kept as nearly as possible to 300 ccs. in each estimation.

The filtrate was then boiled, and 2 grams of Potassium Chromate added for every 100 ccs. of solution. The precipitate was left to stand overnight, after which it was filtered through a glass Gooch crucible. It was washed firstly with a 2% Potassium Chromate solution, secondly with 50% Alcohol, and dried at 120°C.

(b)

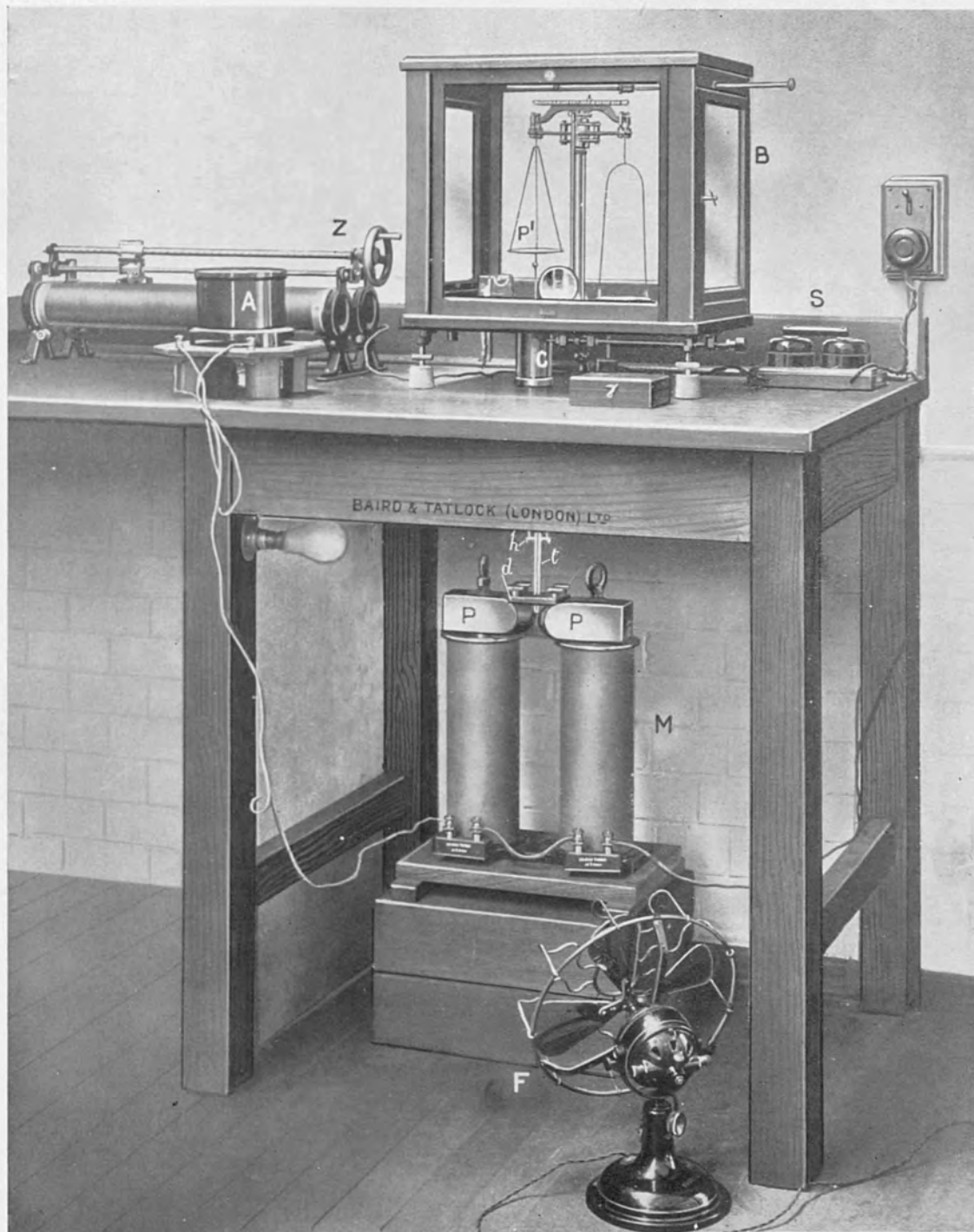
The Cadmium alloys were analysed in a similar manner, but the precipitate of Cadmium Carbonate was washed with dilute Sodium Carbonate solution as it tended to peptise on washing with hot water.

#### COMPARISON OF IODIDE AND CHROMATE METHOD

Analysis of an alloy by Iodide gave 60.09% Thallium.

Analysis of the same alloy by Chromate gave 60.14%

Thallium.



1400.

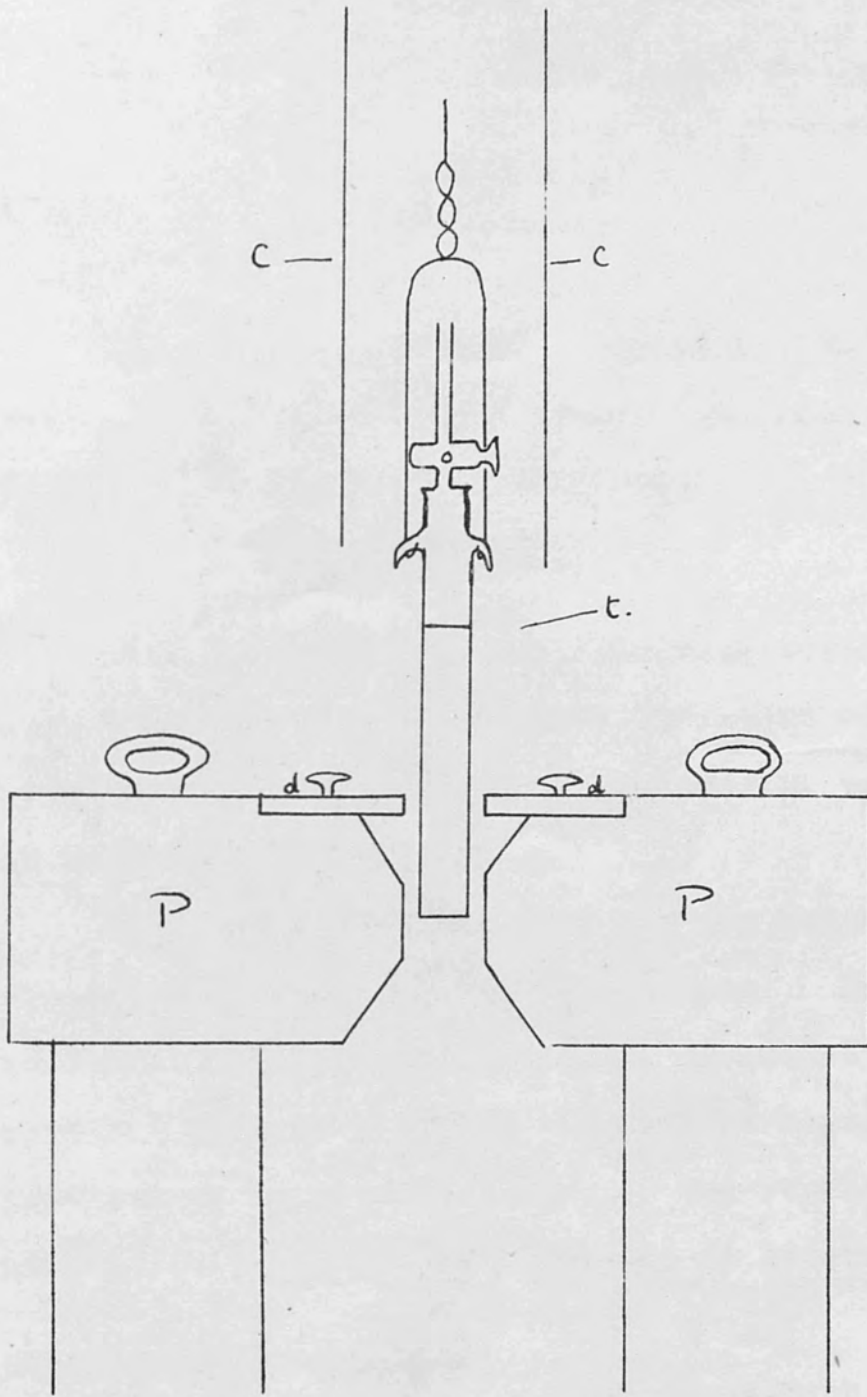


DIAGRAM II

METHOD AND APPARATUS FOR SUSCEPTIBILITY DETERMINATIONS

movable so that the width of the aperture can be varied, and they are screwed to the magnet by means of hand bolts. The width of the aperture is maintained constant by brass

The Magnetic Susceptibility of a substance, K, has been defined as the ratio of the Intensity of Magnetisation, I, to the field, H, producing it, as a glass tube containing

i.e.  $K = \frac{I}{H}$  measured.

The current is controlled by a variable rheostat, R, and is registered by an ammeter, A, in the circuit. The apparatus are in use for the measurement of magnetic susceptibility, and each has its special value for the type of work under investigation.

A specially sensitive balance of the Bunge short beam type, capable of weighing to 0.01 mg. is mounted on the bench about 4 feet above the electro magnet, and is enclosed in a case B. The left-hand scale pan and support are replaced by a light aluminium support and a disc which carries on its lower side a hook. From the hook is suspended a fine platinum wire which passes through a hole

The Gouy method was used for the measurement of the susceptibility of the Thallium alloys. In this, the substance under investigation is suspended by a fine platinum wire in a strong non-uniform magnetic field produced by an electro magnet. The repulsive or attractive force on the substance is determined by weighing.

DESCRIPTION OF APPARATUS (See photograph and diagram 2.)

The apparatus consists essentially of an electro magnet, M, of 20,000 turns, which is capable of carrying a current of 5 amps. Using a current of 3 amps. under a potential of 220 volts, a field of about 5,000 gauss is produced when the aperture between the pole pieces is

1.2 cms. The soft Iron pole pieces, P, are movable so that the width of the aperture can be varied, and they are screwed to the magnet by means of hand bolts. The width of the aperture is maintained constant by brass distance pieces, d, which are screwed into slots in the pole pieces. In the centre of the distance pieces is a circular hole, through which passes a glass tube containing the substance to be measured.

The current is controlled by a variable rheostat, Z, and is registered by an ammeter, A, in the circuit. The current is supplied by the mains, and is switched on and off by a two-pole switch, S.

A specially sensitive balance of the Bunge short beam type, capable of weighing to 0.01 mg. is mounted on the bench about a foot above the electro magnet, and is enclosed in a case B. The left-hand scale pan and support are replaced by a light aluminium support and a disc  $P^1$  which carries on its lower side a hook. From the hook is suspended a fine platinum wire which passes through a hole in the floor of the balance case and bench. To the lower end of this wire is attached a copper stirrup, from which is suspended the tube, t, containing the substance under investigation. The length of the suspension is adjusted so that the inside meniscus of the bottom of the tube is exactly level with a mark on the centre of the pole pieces

of the electro magnet, the latter being arranged so that the gap between the pole pieces is vertically below the hole in the bench.

It was found necessary to protect the suspension from draughts and from convection currents caused by possible overheating of the magnet, as these would have a serious effect on the oscillations by which the weight is obtained. Therefore the part of the suspension between the balance case and the bench was surrounded by a copper tube, C, and the lower part between the tube and the pole pieces protected by a wooden box with a detachable front. The whole of the apparatus below the bench was boarded in to prevent draughts as much as possible.

The alloys under investigation cast in the form of a cylindrical stick are placed in glass tubes about 0.7 cms. in diameter and 13 cms. long, closed at the lower end. The upper end of the tube is closed by a vacuum tap which fits into the tube by means of a ground glass joint. At a distance of 1.5 cms. from the joint are sealed two glass arms, from which the tube is suspended in the copper stirrup. (See diagram 3.).

The stick must be of sufficient length to ensure that the upper end is well outside the magnetic field. The field vertically above the pole pieces was previously explored, the tube being filled with water and gradually

17(a)

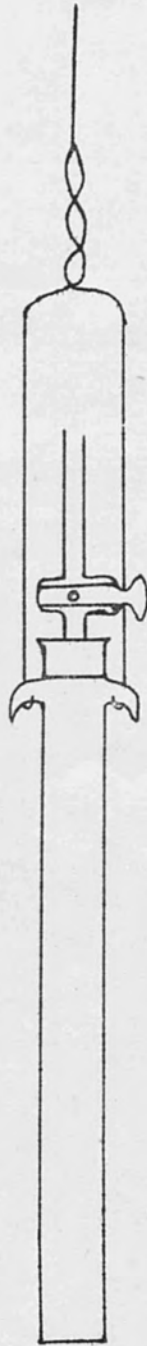


DIAGRAM III.



raised using a shorter and shorter suspension. At a height of 5 cms. above the centre of the pole pieces the pull was only 1 per cent of its original value, becoming zero at 6 cms. above the mark. Hence a stick of length approximately 7.5 cms. was used for all measurements, a mark being etched on the tube this distance from the bottom. The field was found to be constant for 0.4 cms. either above or below the centre of the pole pieces, so that, even when weighing by oscillations, the bottom of the tube was well within the region of uniform maximum field.

The tube containing the substance under investigation is arranged so that it hangs vertically and symmetrically between the pole pieces with its lower end level with the centre mark. Then the tube is weighed by the method of oscillations. The current is then switched on and the resistance adjusted until the ammeter registers 3 amps. The tube and its contents is again weighed and the difference in weight noted. This difference is due to the attraction or repulsion of the substance by the magnet, and from it the magnetic susceptibility may be calculated as follows:-

$$\chi = \frac{W_1 - W_2}{W_1} \cdot \frac{1}{d} + \chi_{\text{air}}$$

$\Delta(H_1^2 - H_2^2)$

If  $A$  = area of cross section of cylinder in sq. cms.

$l$  = length of column of material in cms.

$F$  = pull on material in dynes.

$\mu_1$  = permeability of the material.

$\mu_2$  = permeability of the medium (air).

$K_1$  = volume susceptibility of the material.

$K_2$  = volume susceptibility of the medium.

$H_1$  = field at the bottom of cylinder in gauss.

$H_2$  = field at the top of cylinder in gauss.

The force on material of permeability  $\mu_1$ , suspended in a medium of permeability  $\mu_2$  is given by

$$F = \frac{(\mu_1 - \mu_2) A (H_1^2 - H_2^2)}{8\pi}$$

If  $F$  is measure in milligrams,  $w$  in grams,  $l$  in centimetres and  $A$  in square centimetres, then

$$\mu = 1 + 4K\pi$$

$$\text{i.e. } -F = \frac{1}{2} A (K_1 - K_2) (H_1^2 - H_2^2)$$

$$K_1 = \frac{2F}{A(H_1^2 - H_2^2)} + K_2$$

Mass susceptibility  $\chi = \frac{K}{d}$  where  $d$  = density.

$$\chi d = \frac{2F}{A(H_1^2 - H_2^2)} + \chi_{\text{air}}$$

but  $d = \frac{w}{v}$  where  $w$  = weight of material.

The mean force due to the tube alone was found from the following

$$\chi = \frac{2Fl_s}{w(H_1^2 - H_2^2)} + \chi_{\text{air}} \frac{lA}{w}$$

Temperature.  $w(H_1^2 - H_2^2)$  Weight of tube of tube.  $\chi_{\text{air}}$  Pull on tube. in field.

$H_2$  is zero provided sufficient length of material is used, and  $l$  and  $H_1$  are constant for a given length of column and aperture of pole pieces.

$$\chi_{\text{air}} = 0.03 \times 10^{-6}$$

Hence  $\chi \times 10^6 = \frac{\alpha F}{w} + \frac{v \cdot 0.03}{w}$

where  $\alpha$  is constant for the apparatus.

If  $F$  is measure in milligrams,  $w$  in grams,  $l$  in centimetres and  $A$  in square centimetres, then

$$\alpha = \frac{21 \cdot 10^6 \times 981}{H_1^2 \times 10000} \text{ C.G.S. units.}$$

The constant  $\alpha$  was determined by filling the tube up to the required mark with a pure liquid of known susceptibility and determining the pull. Since glass itself has a susceptibility, the pull on the tube was first determined and this was subtracted from the total pull  $F$ .

The mean force due to the tube alone was found from the following results.

Temperature. °C	Weight of tube.	Weight of tube in field.	Pull on tube.
20°	12.91057 gms	12.90696 gms	-0.00361 gms.
21°	12.91046	12.90687	-0.00359
19°	12.91048	12.90691	-0.00357
22°	12.91043	12.90684	-0.00359
21°	12.92050	12.91691	-0.00359
23°	12.92047	12.91688	-0.00359
20°	12.92048	12.91687	-0.00359

Mean value for small tube = -0.00359 gms.

Measurements for determining pull on second tube.

Temperature.	Weight of tube.	Weight of tube in field.	Pull on tube.
22°	15.95447	15.94259	-0.00188
23°	15.95458	15.94269	-0.00189
23°	15.95471	15.95282	-0.00189
20°	15.94980	15.93789	-0.00191

Mean value for large tube = -0.00189 gms.

The current was then switched on and adjusted to 3 amps.

## METHOD OF MEASUREMENT

The susceptibility tube was washed with Hydrochloric Acid and water, rinsed with Alcohol and Ether, and thoroughly dried. It was then suspended in a copper stirrup attached to a fine platinum wire from the hook on the left hand balance pan. The length of the suspension was carefully adjusted so that the upper meniscus of the lower part of the tube was on a level with a mark on the pole pieces, and so that the tube hung symmetrically between them. The temperature was then recorded by means of a thermometer placed between the pole pieces, and the apparatus was boarded in and left for about ten minutes to allow the tube to become steady.

The tube was then weighed in the usual way to 0.01 gm. the rider being on the zero of the beam. The rider was then moved so that the combined weight of the rider and the weights on the pan was slightly too great. The lever of the balance pan was raised gently so that the pointer swung between 5 - 8 divisions on either side of the zero. Five successive turning points were taken, and the rider moved back along the scale until the combined weights were slightly less than that of the tube. Five turning points were taken as before, and the weight of the tube calculated to within 0.01 grms.

The current was then switched on and adjusted to 3 amps.

by means of the rheostat. It was found that the weight recorded was now too great, so the rider was moved towards the left hand end of the beam until two positions were found in which the combined weight was respectively too light and too heavy. The weight of the tube under the influence of the magnetic field was calculated as before, and the final temperature was recorded.

To minimise the heating of the coils by the current, the magnet was switched off between successive readings, and the readings themselves were taken as quickly as possible. Results were considered unreliable if the temperature rose more than  $1.5^{\circ}\text{C}$  during the measurements. The magnet was cooled by an electric fan in between each complete set of measurements. Several such measurements were made and a mean value taken.

$\lambda$ , the constant of the apparatus, was determined by filling the tube to a definite length with a pure, freshly distilled, organic liquid, and determining the total pull  $F$ , as described. The pull due to the tube was subtracted and thus the pull due to the liquid was obtained. Liquids were used in preference to solids, as recorded susceptibility values of solids proved to be unreliable.

The volume of the tube was determined by finding the weight of pure acetone required to fill the tube up to the given level, and this volume was used throughout the determination of the constant.

The alloys were then placed in the tube and their susceptibility measured. When a satisfactory value had been obtained their position was reversed and a further measurement taken. The length and diameter of the sticks were measured by Vernier calipers, and the value calculated. The mean magnetic susceptibility values were plotted against percentage composition, and a curve obtained.

The stick was then put in the second tube which was placed in an electric furnace and connected to a Megavac pump. The temperature of the furnace was kept at a few degrees below the melting point of the alloy, and the tube exhausted to the lowest pressure obtainable. After three hours heating the tube was allowed to cool slowly, and a measurement was taken. The alloy was then annealed for a second period of three hours, but no further change was observed. The other alloys were therefore annealed in vacuo for three hours, and as an extra precaution, those lying on well defined maxima of the curve were annealed for six hours.

Determination of the constant of the apparatus for a given length of column and a given field.

Since the formula connecting the magnetic susceptibility and the pull on a column of material varies directly as the length and is independent of the cross

Taking further measurements, the results were as follows:-  
 sectional area, the constant was determined with one tube  
 only. Using A.R. Toluene dried and distilled.  $\chi = 0.729 \cdot 10^{-6}$

Temp.	1. Using A.R. Toluene dried and distilled.	Wt. of tube and material.	Constant
	Weight of tube and stopper	= 12.9169 grs.	
	Pull on tube alone	= -0.00359 grs.	
	Length of column	= 7.36 cms.	
18°	Volume of column	= 3.8121 ccs.	
20°	Susceptibility of Toluene	= -0.729 · 10 <sup>-6</sup>	
19°	Temperature	= 19°C.	
22°	Weight of tube and Toluene	= 15.95284 grs.	
	Weight of tube and Toluene in field	= 15.94559	
	Pull F due to tube and Toluene	= -0.00725 grs.	
(2)	<u>Using A.R. Acetone dried and distilled.</u>		
	Pull F' due to field on Toluene	= -0.00366 grs.	

Temp.	Wt. of tube and material.	Weight of Toluene in field.	Pull due to field on tube & material.	Pull due to field on material.	Constant
					= 3.0359 grs.

From the equation,  $\chi \cdot 10^6 = \frac{0.03v}{w} + \frac{\alpha F'}{w}$

Then  $-0.729 = \frac{0.03 \times 3.8121}{3.0359} - \frac{\alpha \cdot 3.66}{3.0359}$

i.e. Mean value  $\alpha = \frac{0.03 \times 3.8121 + 0.729 \times 3.0359}{3.66}$

(3) Using A.R. Nitrobenzene dried and distilled.  
 $\alpha = 0.626$

Temp.	Wt. of tube and material.	Wt. of tube and material in field.	Pull due to field on tube & material.	Pull due to field on material.	Wt. of constant material.
18°	17.14605	17.13893	-0.00712	-0.00353	3.4187



Taking further measurements, the results were as follows:-

(1) Using A.R. Toluene dried and distilled.  $\chi = -0.729 \cdot 10^{-6}$

Temp.	Wt. of tube and material. grs.	Wt. of tube and material in field. grs.	Pull due to field on tube & material. F	Pull due to field on material. F'	Wt. of material. grs. w	Constant.
18°						0.616
19°						0.625
19°						0.621
18°	15.95296	15.94566	-0.00730	-0.00371	3.0361	-0.618
20°	15.94559	15.94559	-0.00725	-0.00366	3.0359	-0.626
19°	15.95271	15.94541	-0.00730	-0.00371	3.0360	-0.618
22°	15.95249	15.94523	-0.00726	-0.00367	3.0357	-0.626

Mean value = 0.622.

(2) Using A.R. Acetone dried and distilled.  $\chi = -0.581 \cdot 10^{-6}$

Temp.	Wt. of tube and material. grs.	Wt. of tube and material in field. grs.	Pull due to field on tube & material. F	Pull due to field on material. F'	Wt. of material. grs. w	Constant.
19°	15.69732	15.69097	-0.00635	-0.00276	2.7804	-0.622
20°	15.70128	15.69494	-0.00634	-0.00275	2.7844	-0.624

Mean value = -0.623

(3) Using A.R. Nitrobenzene dried and distilled.  $\chi = -0.499 \cdot 10^{-6}$

Temp.	Wt. of tube and material. grs.	Wt. of tube and material in field. grs.	Pull due to field on tube & material. F.	Pull due to field on material. F'	Wt. of material. grs. w	Constant.
18°	17.14605	17.13893	-0.00712	-0.00353	4.2189	-0.625

Temp.	Wt. of tube and material. grs.	Wt. of tube and material in field. grs.	Pull due to field on tube & material. F	Pull due to field on material. F'	Wt. of material. grs. w	Constant.
18°	17.13219	17.12503	-0.00716	-0.00357	4.2112	0.616
19°	17.14605	17.13893	-0.00712	-0.00353	4.2191	0.625
19°	17.13489	17.12780	-0.00709	-0.00350	4.2077	0.621

The apparatus is not appreciably affected by magnetic storms and changes in atmospheric conditions, whereas this cause made determinations by the Curie - Chanaveau balance very difficult and at times impossible. The apparatus can

be used continuously and gives good, consistent and reproducible results.

Value of constant used throughout determinations

Every precaution is taken to keep the apparatus free from draughts as the method depends on oscillations. In this set of determinations the weights of material used were sufficiently great to be completely unaffected by slight draughts due to convection currents.

Moisture in the atmosphere causes an alteration of the dielectric constant of air, and the field between the poles of the electromagnet is affected but only by an amount which is practically negligible. Since the method of measurement involves only weighings, it is possible to carry out a complete series of five or six measurements in a day, and therefore atmospheric conditions are approximately the same.

The force on the empty tubes was redetermined from time to time during the measurements and was found to be sensibly constant. Values obtained for the susceptibility of certain of the alloys were found to be unchanged after

an interval DISCUSSION OF METHOD discussing that consistent results can be obtained.

Since it is impossible for the alloys to fit the tube exactly, and also because their surfaces may be slightly uneven, a small error in the experimental work may arise, cause made determinations by the Curie - Cheneveau balance very difficult and at times impossible. The apparatus can be used continuously even in a storm and gives good, consistent and reproduceable results.

Every precaution is taken to keep the apparatus free from draughts as the method depends on oscillations. In this set of determinations the weights of material used were sufficiently great to be completely unaffected by slight draughts due to convection currents.

Moisture in the atmosphere causes an alteration of the dielectric constant of air, and the field between the poles of the electromagnet is affected but only by an amount which is practically negligible. Since the method of measurement involves only weighings, it is possible to carry out a complete series of five or six measurements in a day, and therefore atmospheric conditions are approximately the same.

The force on the empty tubes was redetermined from time to time during the measurements and was found to be sensibly constant. Values obtained for the susceptibility of certain of the alloys were found to be unchanged after

COMPOSITION OF ALLOYS

an interval of several months, showing that consistent results can be obtained.

(1) Since it is impossible for the alloys to fit the tube exactly, and also because their surfaces may be slightly uneven, a small error in the experimental work may arise, due to the volume of air in the tube.

A stick of Cadmium was placed in the susceptibility tube in the usual manner and its magnetic susceptibility determined. It was then removed from the tube and suspended by means of a small hook soldered on to one end. The magnetic susceptibility was again determined and was found to be unchanged. Hence it is evident that any variations in the susceptibility due to slight irregularities are within the limits of experimental error.

	Thallium	Thallium in	Bi.	Bi.
I	62.37	61.41	62.49	63.01
J	70.65	70.56	70.62	71.09
K	76.88	75.96	76.92	77.34
L	80.86	81.47	81.14	81.41
M	92.68	92.14	92.41	92.58

COMPOSITION OF ALLOYS

(2) Cadmium - Thallium alloys.

(1) Bismuth - Thallium alloys.

Alloy.	Percentage weight of Thallium.		Mean Percentage Thallium in stick.	Atoms per cent.	
	1.	2.		Tl.	Bi.
A	7.28%	7.38%	7.34%	7.50%	92.50%
B	21.05	21.24	21.15	21.53	78.47
C	25.39	25.39	25.39	25.80	74.20
D	30.78	30.82	30.80	31.22	68.78
E	34.59	34.41	34.50	35.00	65.00
F	39.28	39.56	39.42	40.37	59.63
G	47.01	47.06	47.04	47.60	52.40
H	54.74	54.95	54.85	55.42	44.58
I	62.37	62.61	62.49	63.01	36.99
J	70.65	70.58	70.62	71.09	28.91
K	76.88	76.96	76.92	77.34	22.66
L	80.86	81.42	81.14	81.41	18.59
M	92.68	92.14	92.41.	92.58	7.42

Calculation of Magnetic Susceptibilities.

Weight of tube used for measurements in air = 12.916 grs.  
 (2) Cadmium - Thallium alloys. = - 0.00359 grs.  
 Weight of tube used for measurements in vacuo = 13.23212 grs.  
 Pull on tube used for measurements in vacuo = - 0.00189 grs.

Alloy.	Percentage weight of Thallium.		Mean Percentage of Thallium.	Atoms per cent.	
	1.	2.		Tl.	Cd.
(1) A	13.50%	13.48%	13.49%	7.91%	92.89%
B	19.29	19.37	19.33	11.69	88.31
C	33.36	33.44	33.40	21.65	78.35
D	41.93	41.95	41.94	28.47	71.53
E	51.02	51.25	51.14	36.57	63.43
F	60.30	59.98	60.14	45.40	54.60
G	70.55	70.61	70.58	56.94	43.06
H	78.77	80.05	79.41	68.22	31.78
I	87.94	87.04	87.49	79.43	20.57

(2) After annealing in vacuo.

23°C	39.15708	39.09942	0.05766	-0.05409
22°C	39.15702	39.09932	0.05770	-0.05434
23°C	39.15701	39.09942	0.05759	-0.05424
23°C	42.88821	42.83025	0.05796	-0.05397
24°C	42.88817	42.83021	0.05810	-0.05421

Pull on empty tube = -0.00359.

Calculation of Magnetic Susceptibilities.

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Weight of tube used for measurements in air = 12.916 grs.  
Pull on tube used for measurements in air = - 0.00359 grs.  
Weight of tube used for measurements in vacuo = 13.23212 grs.  
Pull on tube used for measurements in vacuo = - 0.00189 grs.

for a length of stick 7.36 cms = 0.622

Magnetic Susceptibility of Pure Bismuth.

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(1) In air.

Temp.	Weight of tube and material.	Weight of tube and material in field.	Difference in weight.	Pull on material.
19°C	39.14605 grs.	39.08877 grs.	0.05728 grs.	-0.05369 grs.
18°C	39.14626	39.08886	0.05740	-0.05381
20°C	39.14626	39.08885	0.05741	-0.05382
21°C	39.14627	39.08915	0.05712	-0.05353
20°C	39.14646	39.08944	0.05702	-0.05343

(2) After annealing in vacuo.

23°C	39.15708	39.09942	0.05766	-0.05429
22°C	39.15702	39.09931	0.05771	-0.05434
23°C	39.15701	39.09941	0.05760	-0.05424
23°C	42.88821	42.83235	0.05586	-0.05397
24°C	42.88817	42.83207	0.05610	-0.05421

Pull on empty tube = -0.00337.

BISMUTH - THALLIUM ALLOYS

Alloy A.

Magnetic Susceptibility of Pure Bismuth.

Temp.      Weight of      Difference      Pull on  
 Length of stick      = 7.47 cms.      in weight      material.  
 Diameter of stick      = 0.67 cms.  
 Weight of material      = 26.226 grs.      -0.04227 grs.

Mean Pull on Material (1) -0.05376 grs. (2) -0.05426 grs.

$\chi \times 10^{-6}$       (1) -1.292      (2) -1.320

$$\chi \times 10^{-6} = \frac{7.47 \times 0.622 \times 53.76 + 0.03 \times 7.47 \times (.335)^2}{26.226} = -1.292$$

Weight of material  
 Length of stick  
 Diameter of stick  
 Mean pull on material (1) -0.05376 (2) -0.05426

$\chi \times 10^{-6}$       (1) -1.292      (2) -1.320



**BISMUTH - THALLIUM ALLOYS**

Alloy A.

(1) In air.

Temp.	Weight of tube and material.	Weight of tube and material in fluid.	Difference in weight.	Pull on material.
22°C	40.47615 grs.	40.45175 grs.	0.02440 grs.	-0.01742 grs.
222°C	38.7115 grs.	38.06573 grs.	0.04586 grs.	-0.04227 grs.
223°C	38.71030	38.06443	0.04587	-0.04228
224°C	38.71031	38.06441	0.04590	-0.04231
224°C	38.71024	38.06442	0.04582	-0.04223
21°C	40.47471	40.45175	0.02295	-0.01736

(2) After annealing in vacuo.

Temp.	Weight of material	Weight of material in fluid	Difference in weight	Pull on material
29°C	41.75208	41.70725	0.04483	-0.04294
230°C	41.75520	41.70750	0.04470	-0.04281
230°C	41.75209	41.70731	0.04478	-0.04289
230°C	41.75205	41.70720	0.04485	-0.04296

As the increase in the pull is within the limits of experimental error, no further measurements were taken, and the susceptibility was considered to be unchanged.

Weight of material = 25.794 grs.  
 Length of stick = 7.20 cms.  
 Diameter of stick = 0.69 cms.

Weight of material = 25.794 grs.  
 Mean pull on material (1) -0.04227 (2) -0.04290

Length of stick = 7.20 cms.  
 Diameter of stick = (1) -0.996 (2) -1.010

Mean pull on alloy (1) -0.04227 grs. (2) -0.04290 grs.

Diameter of stick (1) -0.996 (2) -1.010

Alloy B.

(1) In air.

Temp.	Weight of tube and material.	Weight of tube and material in field.	Difference in weight.	Pull on material.
22°C	40.47615 grs.	40.45314 grs.	0.02301 grs.	-0.01942 grs.
23°C	40.47638	40.45324	0.02314	-0.01955
24°C	40.47475	40.45188	0.02287	-0.01928
23°C	40.47470	40.45187	0.02283	-0.01924
20°C	40.47455	40.45154	0.02301	-0.01942
21°C	40.47471	40.45176	0.02295	-0.01936

(2) After annealing in vacuo.

21°C	43.51596	43.49443	0.02153	-0.01964
22°C	43.51804	43.49646	0.02158	-0.01969
23°C	43.51803	43.49655	0.02148	-0.01959

As the increase in the pull is within the limits of experimental error, no further measurements were taken, and the susceptibility was considered to be unchanged.

Diameter of alloy = 0.57 cms.

Weight of material = 27.553 grs.

Length of stick = 7.45 cms.

Diameter of stick = 0.68 cms.

Mean pull on alloy (1) -0.01938 grs. (2) -0.01964 grs.

$\chi \cdot 10^{-6}$  (1) -0.451 (2) -0.451

Alloy C.

(1) In air.

Temp.	Weight of tube and material.	Weight of tube and material in field.	Difference in weight.	Pull on material.
20°C	41.83266 grs.	41.81591 grs.	0.01675 grs.	-0.01316 grs.
22°C	41.83256	41.81580	0.01676	-0.01317
23°C	41.83257	41.81584	0.01673	-0.01314
21°C	41.83260	41.81578	0.01682	-0.01323
23°C	41.83245	41.81562	0.01683	-0.01324

(2) After annealing in vacuo.

Temp.	Weight of alloy	Weight of alloy in field.	Difference in weight.	Pull on alloy
22°C	44.96864	44.95289	0.01575	-0.01386
23°C	44.96871	44.95310	0.01561	-0.01372
24°C	44.96884	44.95306	0.01578	-0.01389
24°C	44.96888	44.95293	0.01595	-0.01406
21°C	44.96830	44.95285	0.01545	-0.01356

Weight of alloy = 29.915 grs.

Length of alloy = 7.55 cms.

Diameter of alloy = 0.67 cms.

Diameter of alloy = 0.69 cms.

Mean pull on alloy (1) -0.01319 grs. (2) -0.01388 grs.

Mean pull on alloy (1) -0.00648 grs. (2) -0.00667

$\times 10^{-6}$  (1) -0.288 (2) -0.304

(1) -0.135 (2) -0.137

Alloy D.

(1) In air.

Temp.	Weight of tube and material.	Weight of tube and material in field.	Difference in weight.	Pull on material.
26°C	42.94500 grs.	42.93489 grs.	0.01011 grs.	-0.00652 grs.
27°C	42.94497	42.93491	0.01006	-0.00647
24°C	42.94490	42.93483	0.01007	-0.00648
23°C	42.94524	42.94518	0.01006	-0.00647

(2) After annealing in vacuo.

21°C	45.98431	45.97567	0.00864	-0.00675
22°C	45.98439	45.97580	0.00859	-0.00670
22°C	45.98420	45.97566	0.00854	-0.00665
21°C	45.98430	45.97585	0.00845	-0.00656

Length of stick = 7.47 cms.

Weight of alloy = 30.028 grs.

Length of alloy = 7.47 cms.

Diameter of alloy = 0.69 cms.

Mean pull on alloy (1) -0.00648 grs. (2) -0.00667

$\chi 10^{-6}$  (1) -0.133 (2) -0.137

Alloy E.

(1) In air. *air.*

Temp.	Weight of tube and material.	Weight of tube and material in field.	Difference in weight.	Pull on material.
25°C	42.79819 grs.	42.79014 grs.	0.00805 grs.	-0.00446 grs.
25°C	42.79818	42.79014	0.00804	-0.00445
26°C	42.79811	42.79011	0.00800	-0.00441
26°C	42.79792	42.78992	0.00800	-0.00441

(2) After annealing in vacuo.

25°C	46.13211	46.12577	0.00634	- 0.00445
26°C	46.13215	46.12578	0.00637	- 0.00448

Weight of alloy = 29.881 grs.

Length of stick = 7.43 cms.

Diameter of stick = 0.69 cms.

Mean pull on alloy (1) -0.00443 grs. (2) unchanged.

$\times 10^{-6}$  (1) -0.090 (2) unchanged.

The difference was *0.00110 grs.*  
of experimental error.

Alloy F.

(1) In the air.

Temp.	Weight of tube and material.	Weight of tube and material in field.	Difference in weight.	Pull on material.
22°C	41.77063 grs.	41.76014 grs.	0.01049 grs.	-0.00690 grs.
22°C	41.77037	41.75986	0.01051	-0.00692
24°C	41.77036	41.75991	0.01045	-0.00686
24°C	41.77059	41.76013	0.01046	-0.00687

(2) After annealing in vacuo.

23°C	45.80062	45.79163	0.00899	-0.00710
24°C	45.80087	45.79178	0.00899	-0.00710
22°C				

Weight of stick = 28.853 grs.

Length of stick = 7.55 cms.

Diameter of stick = 0.684 cms.

Mean pull on stick (1) 0.00689 grs. (2) 0.00710 grs.

$\times 10^{-6}$  (1) -0.145

The difference was considered as being within the limits of experimental error.

Alloy G.

(1) In air.

Temp.	Weight of tube and material.	Weight of tube and material in field.	Difference in weight.	Pull on material.
24°C	43.02618 grs.	43.01542 grs.	0.01076 grs.	-0.00717 grs.
25°C	43.02614	43.01539	0.01075	-0.00716
23°C	43.02694	43.01612	0.01082	-0.00723
22°C	43.02670	43.01588	0.01082	-0.00723
23°C	42.36563	42.35928	0.00635	-0.00679

(2) After annealing in vacuo.

23°C	46.05307	46.04420	0.00887	-0.00698
23°C	46.05302	46.04414	0.00888	-0.00699
22°C	46.05315	46.04419	0.00896	-0.00707
23°C	46.05314	46.04426	0.00888	-0.00699
24°C	45.69199	45.68270	0.00929	-0.00660

Weight of stick = 30.109 grs.

Length of stick = 7.56 cms.

Diameter of stick = 0.69 cms.

Diameter of alloy = 0.485 cms.

Mean pull on stick (1) -0.00720 grs. (2) -0.00701

Mean pull on stick (1) 0.00716 grs. (2) 0.00700 grs.

$\times 10^{-6}$   
 $\times 10^{-6}$

(1) -0.150 (2) -0.147

(1) -0.150 (2) -0.147

Alloy H.

(1) In air.

Temp.	Weight of tube and material.	Weight of tube and material in field.	Difference in weight.	Pull on material.
20°C	42.36566 grs.	42.35529 grs.	0.01037 grs.	-0.00678 grs.
21°C	42.36567	42.36533	0.01034	-0.00675
21°C	42.36572	42.36539	0.01033	-0.00674
22°C	42.36565	42.35530	0.01035	-0.00676
23°C	42.36563	42.35528	0.01038	-0.00679

(2) After annealing in vacuo.

22°C	45.69191	45.68341	0.00850	-0.00661
23°C	45.69188	45.68340	0.00848	-0.00659
24°C	45.69215	45.68360	0.00855	-0.00666
24°C	45.69199	45.68350	0.00849	-0.00660

Weight of alloy = 29.448 grs.  
 Length of alloy = 7.242 cms.  
 Diameter of alloy = 0.680 cms.

Mean pull on alloy (1) 0.00676 grs. (2) 0.00660 grs.

$\times 10^{-6}$   
 (1) -0.138 (2) -0.125



Alloy I.

(1) In air.

Temp.	Weight of tube and material.	Weight of tube and material in field.	Difference in weight.	Pull on material.
20°C	43.50150 grs.	43.49229 grs.	0.00921 grs.	-0.00562 grs.
22°C	43.50154 grs.	43.49232	0.00922	-0.00563
22°C	43.50181	43.49264	0.00917	-0.00558
22°C	43.50167	43.49245	0.00922	-0.00563

(2) After annealing in vacuo.

24°C	46.53356	46.52623	0.00733	-0.00544
25°C	46.53353	46.52617	0.00736	-0.00547
26°C	46.53343	46.52615	0.00730	-0.00541
26°C	46.53359	46.52626	0.00733	-0.00544

Weight of alloy = 30.584 grs.

Length of alloy = 7.53 cms.

Diameter of alloy = 0.68 cms.

Mean pull on alloy (1) 0.00562 grs. (2) 0.00544 grs.

$\times 10^{-6}$

(1) -0.114

(2) -0.110

Alloy J.

(1) In air.

Temp.	Weight of tube and material.	Weight of tube and material in field.	Difference in weight.	Pull on material.
24° C	46.01755 grs.	46.01101 grs.	0.00654 grs.	- 0.00295 grs
25° C	46.01764	46.01112	0.00652	- 0.00293
26° C	46.01781	46.01132	0.00648	- 0.00295
27° C	46.01784	46.01128	0.00656	- 0.00297

(2) After annealing in vacuo.

23° C	49.05583	49.05126	0.00457	- 0.00268
24° C	49.05583	49.05125	0.00458	- 0.00269
22° C	49.05570	49.05114	0.00456	- 0.00267
23° C	49.05572	49.05117	0.00455	- 0.00266

Weight of alloy = 34.100 grs.

Length of alloy = 7.53 cms.

Diameter of alloy = 0.68 cms.

Mean pull on alloy (1) 0.00295 grs. (2) 0.00267 grs.

$\chi_{10}^{-6}$

(1) -0.059

(2) -0.054

Alloy K.

(1) In air.

Temp.	Weight of tube and material.	Weight of tube and material in field.	Difference in weight.	Pull on material.
17°C	43.51208 grs.	43.50282 grs.	0.00926 grs.	-0.00567 grs.
18°C	43.51215	43.50285	0.00930	-0.00571
20°C	43.51218	43.50291	0.00927	-0.00568
21°C	43.51204	43.50275	0.00929	-0.00570

(2) After annealing in vacuo.

27°C	46.51935	46.51182	0.00753	-0.00564
26°C	46.51940	46.51186	0.00754	-0.00565
27°C	46.51941	46.51191	0.00750	-0.00561
27°C	46.51936	46.51180	0.00756	-0.00567

Weight of alloy = 30.595 grs.

Length of alloy = 7.40 cms.

Diameter of alloy = 0.676 cms.

Mean pull on alloy (1) 0.00569 grs. (2) 0.00564 grs.

$\chi 10^{-6}$

(1) -0.117

(2) -0.112

Alloy L.

(1) In air.

Temp.	Weight of tube and material.	Weight of tube and material in field.	Difference in weight.	Pull on material.
23° C	45.24112 grs.	45.23190 grs.	0.00922 grs.	-0.00563 grs.
24° C	45.24112	45.23186	0.00926	- 0.00567
23° C	45.24100	45.23176	0.00924	- 0.00565
24° C	45.24099	45.23170	0.00929	- 0.00570
22° C	44.80126	44.78946	0.01180	- 0.00821
20° C	44.80123	44.78949	0.01179	- 0.00820

(2) After annealing in vacuo.

22° C	48.42692	48.41917	0.00775	- 0.00586
23° C	48.42694	48.41909	0.00785	- 0.00596
21° C	48.42703	48.41923	0.00780	- 0.00591
21° C	48.42614	48.41834	0.00780	- 0.00591

Weight of alloy = 32.324 grs.

Length of alloy = 7.57 cms.

Diameter of alloy = 0.69 cms.

Mean pull on alloy (1) 0.00566 grs. (2) 0.00591 grs.

$\times 10^{-6}$  Mean pull on alloy (1) -0.110 (2) -0.114

Alloy M.  
Pure Thallium

(1) In air.

Temp.	Weight of tube and material.	Weight of tube and material in field.	Difference in weight.	Pull on material.
21° C	44.80134 grs.	44.78951 grs.	0.01183 grs.	- 0.00824 grs.
20° C	44.80126	44.78945	0.01181	- 0.00822 grs.
21° C	44.80122	44.78942	0.01180	- 0.00821
22° C	44.80126	44.78946	0.01180	- 0.00821
20° C	44.80128	44.78949	0.01179	- 0.00820

Weight of alloy

Length of alloy

(2) After annealing in vacuo.

Diameter of alloy

27° C	47.84403 grs.	47.83399	0.01004	- 0.00815
28° C	47.84409	47.83418	0.00991	- 0.00802
26° C	47.84212	47.83214	0.00998	- 0.00809
27° C	47.84219	47.83222	0.00997	- 0.00808

When an attempt was made to pull on the metal attached to the alloy

Weight of alloy = 31.884 grs.

Length of alloy = 7.53 cms.

Diameter of alloy = 0.68 cms.

Mean pull on alloy (1) 0.00822 (2) 0.00808

$\chi 10^{-6}$

(1) -0.161 (2) -0.159

Pure Thallium

Temp.	Weight of tube and material.	Weight of tube and material in field.	Difference in weight.	Pull on material.
20°C	43.82813 grs.	43.81338 grs.	0.01475 grs.	-0.01116 grs.
21°C	43.82812	43.81338	0.01474	-0.01115
20°C	43.82816	43.81338	0.01478	-0.01119
20°C	43.82795	43.81320	0.01475	-0.01116

Weight of alloy = 30.911 grs.

Length of alloy = 7.35 cms.

Diameter of alloy = 0.68 cms.

Mean pull on alloy = 0.1117 grs.

$\chi 10^{-6}$  of alloy = -0.223 grs.

When an attempt was made to anneal the Thallium in vacuo, the metal attacked the glass, forming a yellow film.

CADMIUM - ZINC ALLOYS

Cadmium

Temp.	Weight of tube and material.	Weight of tube and material in field.	Difference in weight.	Pull on material.
20° C	36.55567 grs.	36.54584 grs.	0.00983 grs.	- 0.00624 grs.
20° C	36.55567	36.54586	0.00981	- 0.00622
21° C	36.55577	36.54600	0.00977	- 0.00618
21° C	36.55580	36.54597	0.00983	- 0.00624

The second series of measurements could not be made as the Cadmium volatilised in a vacuum.

Weight of alloy = 23.638 grs.

Length of alloy = 7.47 cms.

Diameter of alloy = 0.69 cms.

Mean pull on alloy = -0.00622 grs.

$\times 10^{-6}$  = -0.163

Alloy B.

CADMIUM - THALLIUM ALLOYS

(1) In air.

Alloy A.

Temp.	Weight of tube and material.	Weight of tube and material in field.	Difference in weight.	Pull on material.
21°C	37.23845	37.22809	0.01036	-0.00677
22°C	36.87713			
22°C	37.23845 grs.	37.22809 grs.	0.01036 grs.	-0.00677 grs.
23°C	37.23845	37.22809	0.01036	-0.00677
24°C	37.23870	37.22834	0.01036	-0.00677

(2) After annealing in vacuum.

Weight of alloy = 24.321 grs.  
 Length of alloy = 7.50 cms.  
 Diameter of alloy = 0.69 cms.  
 Mean pull on alloy = -0.00677 grs.

$\times 10^6$  of alloy = -0.174  
 Length of alloy = 7.46 cms.  
 Diameter of alloy = 0.68 cms.

Mean pull on alloy (1) 0.00677

$\times 10^6$  (1) 0.174



Alloy B.

(1) In air.

Temp.	Weight of tube and material.	Weight of tube and material in field.	Difference in weight.	Pull on material.
21°C	36.87706 grs.	36.86665 grs.	0.01041 grs.	- 0.00682 grs.
22°C	36.87713	36.86667	0.01045	- 0.00686
22°C	36.87711	36.86665	0.01046	- 0.00687
23°C	36.87686	36.86640	0.01046	- 0.00687

(2) After annealing in vacuo.

30°C	40.20536	40.19640	0.00896	- 0.00707
31°C	40.20552	40.19660	0.00892	- 0.00703
30°C	40.20543	40.19651	0.00892	- 0.00703
31°C	40.20556	40.20659	0.00897	- 0.00708

Weight of alloy = 23.908 grs.

Length of alloy = 7.46 cms.

Diameter of alloy = 0.68 cms.

Mean pull on alloy (1) 0.00687 grs. (2) 0.00708 grs.

$\gamma \cdot 10^{-6}$

(1) -0.178

(2) -0.182

Alloy C.

Temp.	Weight of tube and material.	Weight of tube and material in field.	Difference in weight.	Pull on material.
22° C	38.03557 grs.	38.02438 grs.	0.01139 grs.	-0.00780 grs.
23° C	38.03963 grs.	38.02823 grs.	0.01140 grs.	-0.00781 grs.
22° C	38.03577	38.02436	0.01141	-0.00782
23° C	38.03966	38.02826	0.01140	-0.00781
24° C	39.14043	39.12861	0.01182	-0.00823

Weight of alloy = 25.118 grs.

Length of alloy = 7.42 cms.

Diameter of alloy = 0.69 cms.

Mean pull on alloy = 0.00781 grs.

$\chi 10^{-6}$  of alloy = -0.192 grs.

Length of alloy = 7.45 cms.

Diameter of alloy = 0.68 cms.

Mean pull on alloy = -0.00820 grs.

$\chi 10^{-6}$  = -0.194

The difference in (1) and (2) is within the limits of experimental error.

Alloy D.

(1) In air.

Temp.	Weight of tube and material.	Weight of tube and material in field.	Difference in weight.	Pull on material.
24° C	39.14026 grs.	39.12848 grs.	0.01178 grs.	-0.00819 grs.
24° C	39.14028	39.12849	0.01179	-0.00820
25° C	39.14034	39.12858	0.01176	-0.00817
24° C	39.14043	39.12861	0.01182	-0.00823

(2) After annealing in vacuo.

28° C	42.17670 grs.	42.16650	0.01020	-0.00831
28° C	42.17668	42.16646	0.01022	-0.00833

Weight of alloy = 26.223 grs.

Length of alloy = 7.45 cms.

Diameter of alloy = 0.68 cms.

Mean pull on alloy = -0.00820 grs.

$$\chi 10^{-6} = -0.194$$

The difference in (1) and (2) is within the limits of experimental error.

Alloy E.

(1) In air.

Temp.	Weight of tube and material.	Weight of tube and material in field.	Difference in weight.	Pull on material.
17°C	40.05282 grs.	40.04069 grs.	0.01213 grs.	-0.00854 grs.
18°C	40.05275	40.04060	0.01215	-0.00856
19°C	40.05264	40.04051	0.01213	-0.00854
19°C	40.05250	40.04036	0.01214	-0.00855

(2) After annealing in vacuum  
Weight of alloy = 27.135 grs.

Length of alloy = 7.49 cms. 0.01039 -0.00850 grs.

Diameter of alloy = 0.69 cms. 0.01039 -0.00850

21°C 42.96150 42.96225 0.01045 -0.00856

20°C 42.96156 42.95105 0.01051 -0.00852

$\times 10^{-6}$  = -0.196

Weight of alloy = 26.708 grs.

Length of alloy = 7.20 cms.

Diameter of alloy = 0.67 cms.

Mean pull on alloy (1) -0.00850 grs. (2) -0.00854 grs.

$\times 10^{-6}$  (1) -0.198 (2) -0.184

Alloy F.

(1) In air.

Temp.	Weight of tube and material.	Weight of tube and material in field.	Difference in weight.	Pull on material.
25°C	39.62555 grs.	39.61312 grs.	0.01243 grs.	-0.00884 grs.
24°C	39.62550	39.61312	0.01238	-0.00879
21°C	39.62544	39.61307	0.01237	-0.00878
22°C	39.62555	39.01318	0.01236	-0.00878

(2) After annealing in vacuo.

20°C	42.96147	42.95108	0.01039	-0.00850 grs.
21°C	42.96167	42.95129	0.01039	-0.00850
21°C	42.96150	42.96105	0.01045	-0.00856
20°C	42.96156	42.95105	0.01051	-0.00862

Weight of alloy = 26.708 grs.

Length of alloy = 7.20 cms.

Diameter of alloy = 0.67 cms.

Mean pull on alloy (1) -0.00880 grs. (2) -0.00854 grs.

$\times 10^{-6}$  (1) -0.198 (2) -0.184

Alloy G.

(1) In air.

Temp.	Weight of tube and material.	Weight of tube and material in field.	Difference in weight.	Pull on material.
22°C	42.18288 grs.	42.16955 grs.	0.01333 grs.	-0.00974 grs.
24°C	42.18282	42.16959	0.01326	-0.00967
24°C	42.18306	42.16970	0.01336	-0.00977
23°C	42.18300	42.16968	0.01332	-0.00973

(2) After annealing in vacuum.

Weight of alloy	=	29.265 grs.		
Length of alloy	=	7.57 cms.	0.01212	-0.01023
Diameter of alloy	=	0.69 cms.	0.01219	-0.01030
Mean pull on alloy	=	-0.00973 grs.	0.01218	-0.01027
			0.01226	-0.01037

$\chi 10^{-6} = -0.200$

Weight of alloy	=	29.137 grs.		
Length of alloy	=	7.52 cms.		
Diameter of alloy	=	0.68 cms.		

Mean pull on alloy (1) -0.01000 grs. (2) -0.01037 grs.

$\chi 10^{-6}$  (1) -0.216 (2) -0.223

Alloy H.

(1) In air.

Temp.	Weight of tube and material.	Weight of tube and material in field.	Difference in weight.	Pull on material.
25°C	42.07421 grs.	42.06069 grs.	0.01352 grs.	-0.00993 grs.
26°C	42.07423	42.06064	0.01359	-0.01000
25°C	42.07453	42.06094	0.01359	-0.01000
24°C	42.07440	42.06074	0.01366	-0.01007

(2) After annealing in vacuo.

21°C	45.11495	45.10283	0.01212	-0.01023
23°C	45.11501	45.10282	0.01219	-0.01030
21°C	45.11477	45.10259	0.01218	-0.01029
21°C	45.11487	45.10261	0.01226	-0.01037

Weight of alloy = 29.157 grs.

Length of alloy = 7.52 cms.

Diameter of alloy = 0.68 cms.

Mean pull on alloy (1) -0.01000 grs. (2) -0.01037 grs.

$\times 10^{-6}$

(1) -0.216

(2) -0.223

Alloy I.

Temp.	Weight of tube and material.	Weight of tube and material in field.	Difference in weight.	Pull on material.
23°C	43.36063 grs.	43.34632 grs.	0.01431 grs.	-0.01072 grs.
24°C	43.36083	43.34644	0.01439	-0.01080
24°C	43.36084	43.34654	0.01430	-0.01071
25°C	43.36077	43.34641	0.01436	-0.01077

Weight of alloy = 30.443 grs.

Length of alloy = 7.45 cms.

Diameter of alloy = 0.68 cms.

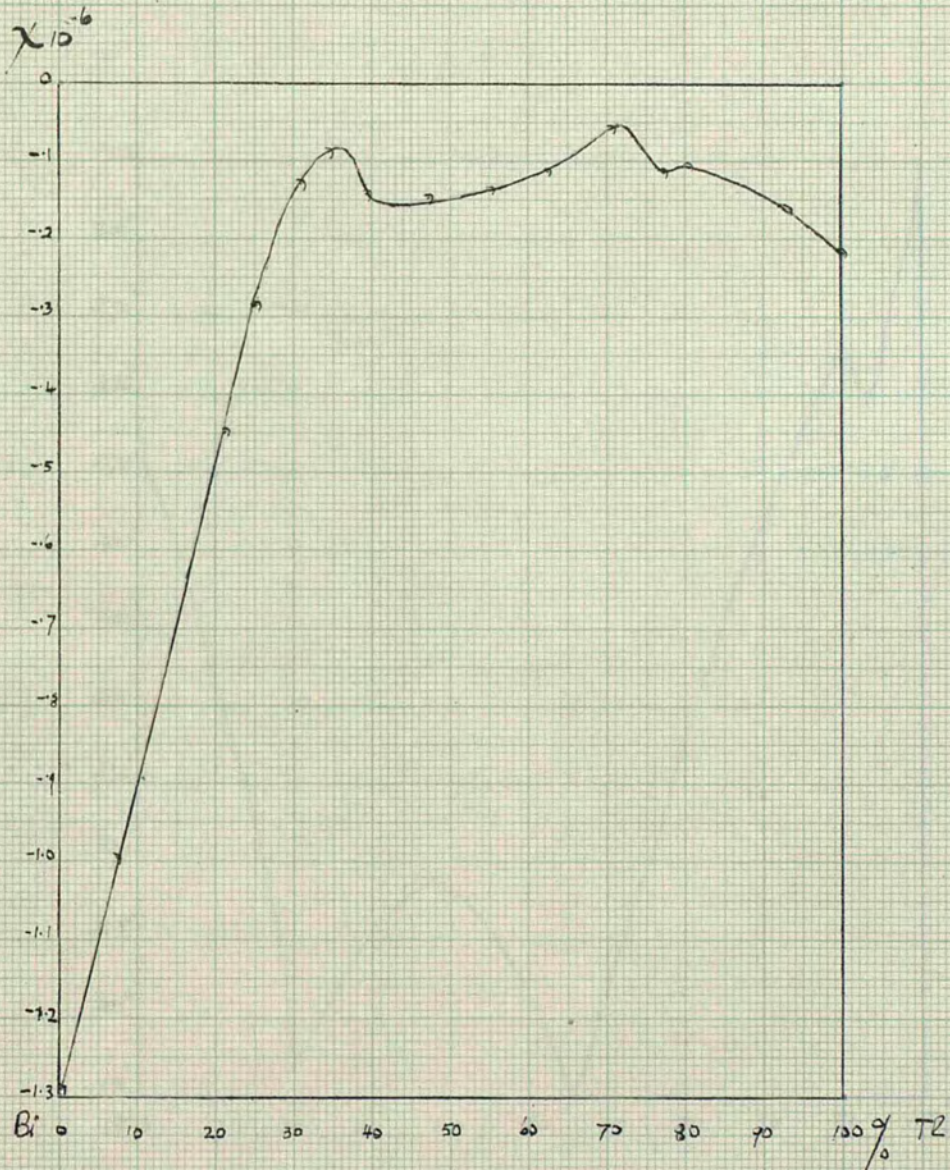
Mean pull on alloy = -0.01075 grs.

$\times 10^{-6}$  = -0.220



(i)

Bismuth - Thallium Alloys.  
Susceptibility - Concentration Curve.



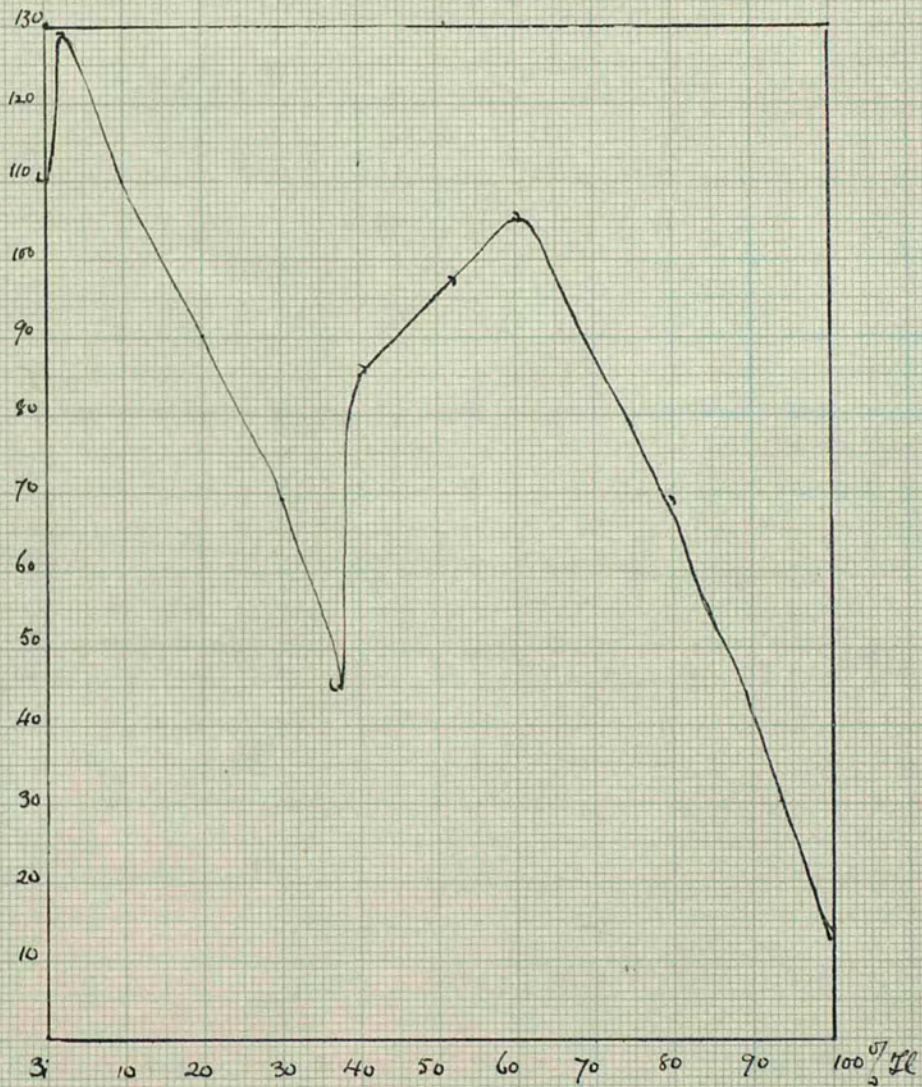
(ii)

Bismuth - Gallium  
Freezing Point Curve (Hergack & Leville<sup>26</sup>)



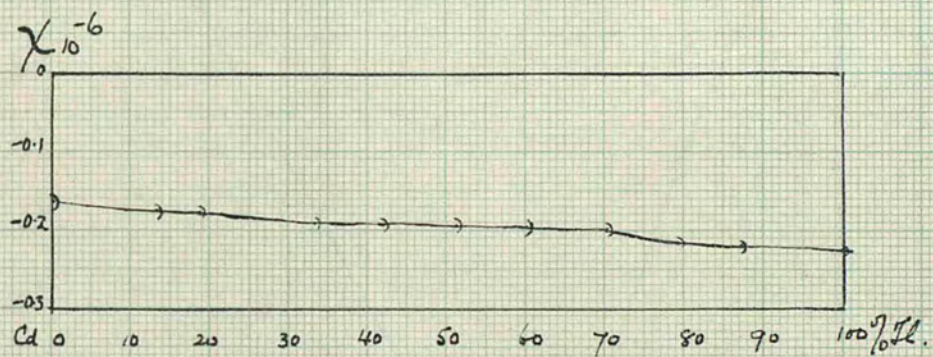
(iii)

Bismuth - Gallium  
Electrical Resistivity (Guenther & Schulze) <sup>28</sup>



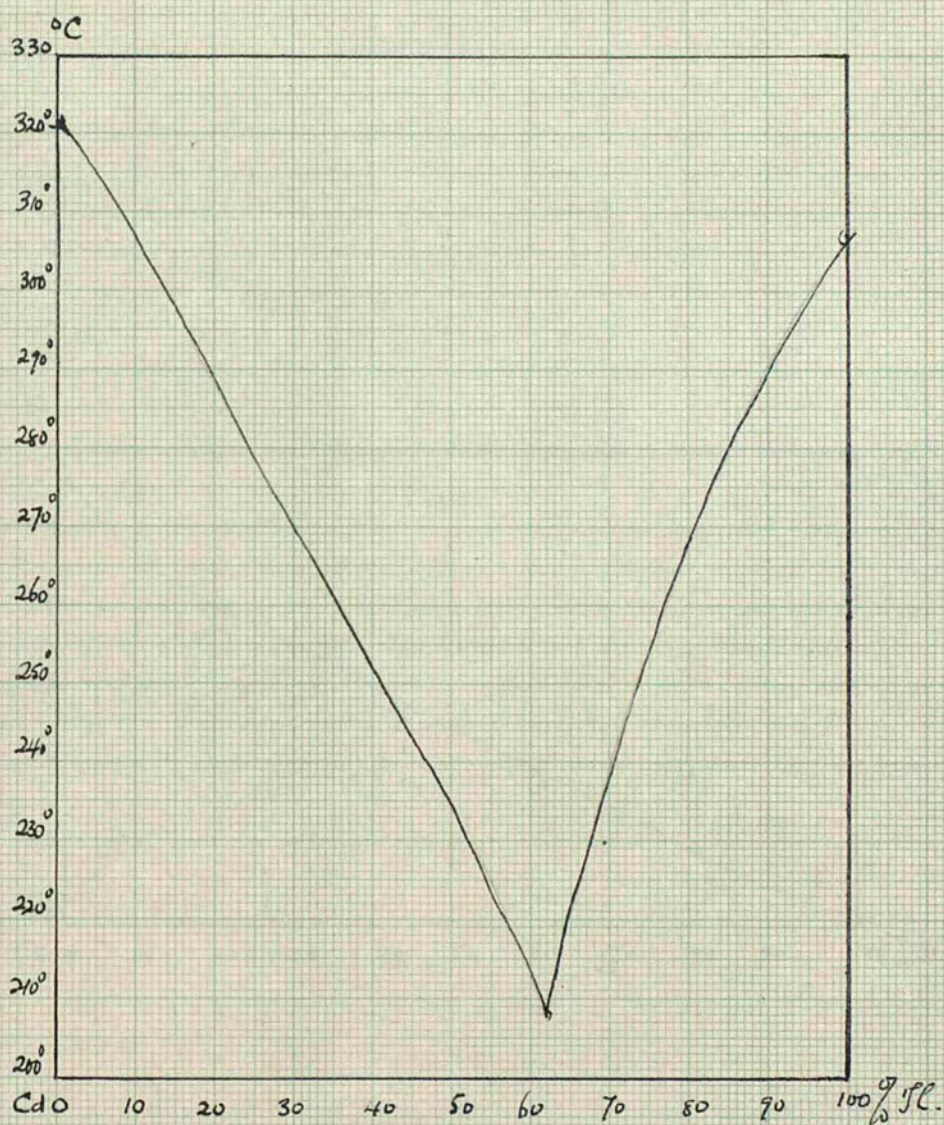
(iv)

Cadmium - Thallium.  
Susceptibility - Concentration Curve.

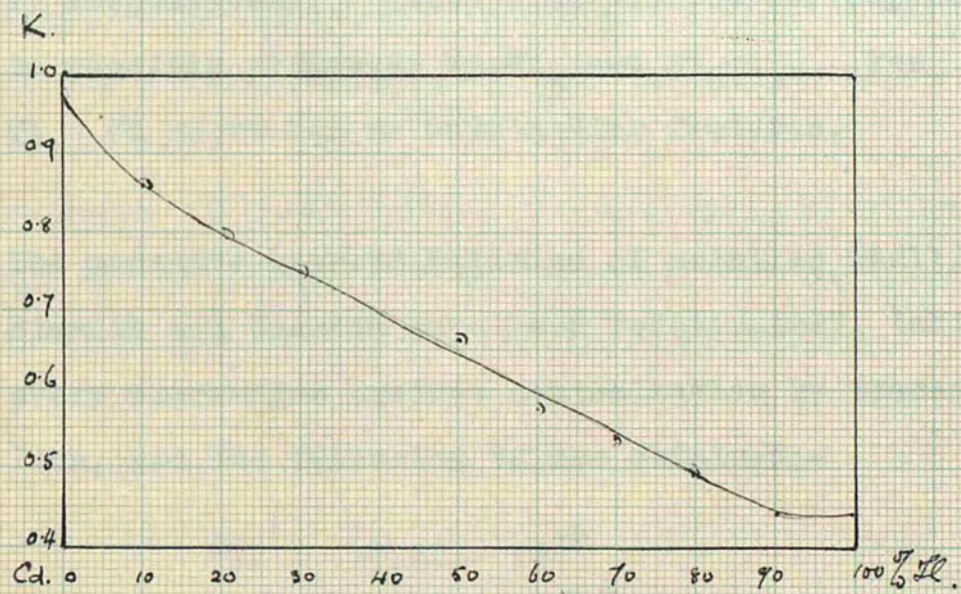


(4)

Cadmium - Thallium  
Freezing Point Curve (J.C.T)



Cadmium - Gallium -  
Thermal Conductivity Curve (Smith)



SUMMARY OF RESULTS

- (1) The susceptibility - composition curves for a complete series of alloys of Tl - Bi and Tl - Cd respectively have been produced. The Tl - Bi curve shows two well defined maxima at points corresponding to alloys containing 36 per cent and 71 per cent of Tl respectively. These compositions correspond to possible compounds  $\text{Bi}_5\text{Tl}_3$  and  $\text{Bi}_2\text{Tl}_3$ . The Tl - Cd curve has no outstanding features.
- (2) The magnetic susceptibilities of metallic Thallium, Bismuth and Cadmium have been redetermined, taking every precaution against contamination by traces of Iron, and the following values obtained:-
- |     |                        |
|-----|------------------------|
| Tl. | $-0.223 \cdot 10^{-6}$ |
| Bi. | $-1.292 \cdot 10^{-6}$ |
| Cd. | $-0.163 \cdot 10^{-6}$ |
- (3) The alloys were annealed and remeasured in vacuo and small changes in susceptibility of the order

of slightly less than plus or minus 2 per cent in the case of Bi - Tl and Tl - Cd were found. In some cases no changes were observed.

- (1) Bi The exceptions were the values for pure Bismuth and the alloy containing 92.66 per cent Bismuth, which showed an increase in negative susceptibility of approximately 23 per cent and 14 per cent respectively.

- (4) A method is described for the estimation of Thallium in the presence of Bismuth and Cadmium.

- (5) Evidence is furnished for the existence of  $Tl_3Bi_5$ , and the existence of this intermetallic compound is confirmed by the results of other workers.

malleable alloy melting at  $211.7^\circ C$ . Since Thallium does not normally form compounds in which it is divalent,  $Tl_3Bi_2$  is probably a mixture of  $Tl_2Bi$  and  $Bi$ . The freezing point curves indicate  $Tl_3Bi$  with a transition point at  $90^\circ C$ .

Observations of Kramann and Lobinger on the E.M.F. of cells with these alloys as electrodes agree with the existence of the tri and penta bismuthides. Further proof was furnished by the study of Thermal



Expansion of Bi-Tl alloys. Thermo-electric properties by S. van Aubel.

DISCUSSION OF RESULTS

(1) Bi - Tl susceptibility - concentration curve.

The curve obtained from electrical conductivity measurements is sharply defined. The maxima observed at points corresponding to concentrations of 36 per cent and 71 per cent Tl respectively suggest that the compounds  $\text{Bi}_5\text{Tl}_3$  and  $\text{Bi}_2\text{Tl}_3$  are present. There is no further evidence for the presence of other compounds.

A similar curve has previously been obtained by Medenhall and Lent;<sup>25</sup> this gave evidence of the existence of intermetallic compounds of similar composition. The freezing point curve fails to indicate the presence of intermetallic compounds.

The freezing point curve produced by Heycock and Neville<sup>26</sup> indicated the presence of  $\text{Bi}_5\text{Tl}_3$ , and this compound was isolated as a soft, easily malleable alloy melting at  $211.7^\circ\text{C}$ . Since Thallium does not normally form compounds in which it is

(2) Bi - Tl freezing point curves indicate  $\text{Tl}_3\text{Bi}$  with a transition point at  $90^\circ\text{C}$ .

Observations of Kremann and Lobinger on the E.M.F. of cells with these alloys as electrodes agree with the existence of the tri and penta bismuthides. Further proof was furnished by the study of Thermal

Expansion by Omodei and of the Thermo-electric properties by E. Van Aubel.<sup>27</sup>

The curve obtained from electrical conductivity measurements by Guertler and Schulze<sup>28</sup> has a sharply defined minimum corresponding to the compound  $\text{Bi}_5\text{Tl}_3$ , but there is no indication of  $\text{Tl}_3\text{Bi}$ . A maximum occurs at a concentration of 60 per cent Tl, which suggests  $\text{Tl}_2\text{Bi}$ , but there is no further evidence for the existence of such a compound.

The Cd - Tl susceptibility - concentration curve shows no marked irregularities, and the investigation of other properties fails to indicate the presence of intermetallic compounds. The freezing point curve has an eutectic point at a temperature of approximately  $200^\circ\text{C}$ . and a concentration of 62 per cent Cd. The thermal conductivity curve produced by Smith has no outstanding features.

- (2) The susceptibility values for Tl, Bi and Cd compare with previous determinations as follows:-

Results obtained.                      Results of other workers.

Cd.  $-0.163 \cdot 10^{-6}$                        $-0.18 \cdot 10^{-6}$                       Honda<sup>29</sup>  
20°C.                                      20°C.

$-0.18 \cdot 10^{-6}$                       Owen<sup>30</sup>

(3) The changes observed in the  $-0.16 \cdot 10^{-6}$                       Shimizu<sup>31</sup>

Bi.  $-1.292 \cdot 10^{-6}$                        $-1.40 \cdot 10^{-6}$                       Honda  
20°C.                                      20°C.)

$-1.38 \cdot 10^{-6}$                       )  
18°C.)

$-1.39 \cdot 10^{-6}$                       Shimizu

Tl.  $-0.223 \cdot 10^{-6}$                        $-0.23$  for Tl                      Honda  
20°C.

The values obtained by Honda always allowed for the presence of small quantities of Iron, and this probably accounts for the larger negative value.

The value obtained for Cadmium agrees with that obtained by Shimizu.

The value  $-1.292$  for Bismuth is small compared with the results obtained by other workers.

Annealing in vacuo increases the negative value to  $-1.320$ , and this is probably due to an alteration

(4) in crystal structure. A similar effect was observed by Medenhall and Lent.<sup>32</sup>

gave very satisfactory results. Complete

The low values obtained are not due to the presence of Iron, as repeated tests failed to indicate the smallest traces of that metal.

- (3) The changes observed in the magnetic susceptibilities of the alloys after annealing in vacuo at a temperature slightly below their melting point were found to be within the limits of experimental error.

This does not confirm the results of Y. Shimizu who states that similar treatment of the systems Gold - Silver, Gold - Copper, Bismuth - Tin, Bismuth - Lead, Antimony - Lead, and Bismuth - Tellurium resulted in a marked increase in negative susceptibility. He therefore claims that the irregular curves obtained by Spencer and John and H. Endo<sup>33</sup> are due to the presence in the alloys of absorbed gases.

Further proof of the existence of the compounds of Bismuth and Thallium indicated by the susceptibility-concentration curves is furnished by the examination of other physical properties, and has been discussed previously.

- (4) The method described for the estimation of Thallium in the presence of Cadmium and Bismuth respectively gave very satisfactory results. Complete

precipitation of Cadmium and Bismuth was achieved, and an accurate estimation of the Thallium content was possible.

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